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Methods of Testing Transformer Oil

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METHODS OF TESTING TRANSFORMER OIL

BY

EDWARD HARDENBERGH WALDO

A. B. Amherst College

M. E. Cornell University

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

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IN ELECTRICAL ENGINEERING

IN

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May 31 1913

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Edward Hardenbergh Waldo

ENTITLED Methods of Testing Transformer Oil.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Master of Science in Electrical Engineering

Ernst Berg
In Charge of Major Work

Ernst Berg
Head of Department

Recommendation concurred in:

Morgan Brooks
J. M. Bryant
Ellery B. Paine

Committee on Final Examination

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METHODS OF TESTING TRANSFORMER OIL

I. INTRODUCTION

A large amount of work has been done in testing the dielectric strength of transformer oils, and much experimentation has been undertaken in attempts to obtain a method giving consistent results. Although such names as Steinmetz, Ryan, Digby and others are among these experimenters, there is not yet a method that will give closely accordant values, especially for different tests and with different operators. A brief synopsis of some of this work is given in the thesis of Foersterling and Mann, University of Illinois 1911, who continued the work begun in the Electrical Department, on oil testing, in 1910.

The ordinary method employed is that of determining the voltage necessary to cause breakdown of the oil between metal spheres of a specified diameter and placed a given distance apart. Considerable attention has been paid to the shape of electrodes, and it has been determined in this laboratory that not only the surface of the electrode itself, but also the size and shape of the conductors leading to it, occasion decided variation in the striking voltage. More consistent data also have been obtained by approaching a pair of terminals between which a fixed difference of potential is maintained, until breakdown occurs. Still better results have been obtained by forcing a stream of oil past the electrodes, care being taken, at the same time, to frequently clean the terminals.

It is not possible at this time to say whether Professor Ryan's suggestion is correct, that breakdown occurs from ions in the oil, or whether some other cause must be assigned. During last year Mr. C. F. Bennett in a further study on "Potential Stresses in Dielectrics," -- Thesis for Master's degree 1912 -- concluded that both breakdown and the erratic results observed were entirely due to the minute bubbles of air and moisture, which were by chance lined up at any time in the electric field, and which were drawn into line between the electrodes. Corona forming within the bubbles, both brings the bubbles more rapidly into the field and starts breakdown of the oil. A circulation of the oil would tend to prevent the formation of a chain of bubbles, and thus give more uniform results. Mr. Bennett's suggestion, however, is that a still better way would be to prevent <u>all</u> circulation, and to this end he developed the process of absorbing the oil in a pure blotting paper and placing the sample so prepared in an electric field for test. He succeeded later in obtaining some quite satisfactory data indicating that the moisture content of oil could be quite accurately determined by this method. The work done in connection with the present thesis has been an attempt to duplicate his results and answer some questions suggested by his statements. Some of his conclusions will be discussed later.

II. DESCRIPTION OF APPARATUS AND METHOD

The test apparatus used was made by Mr. Bennett and described in detail by him. As shown in Fig. 1 and Fig. 2, it consists of two electrodes, one flat and fixed, the other slightly curved and moveable, both having quite sharp edges. This form has been found to give excellent results, the breakdown usually occurring quite near the middle of the field, when the terminals are correctly lined, and when blotting paper about .025" thick is used. The paper well fills the space between the electrodes and little circulation of oil can occur. A light spring on the moveable electrode holds the test piece between the terminals leaving no space unfilled.

The blotting paper, cut into squares slightly larger than the electrodes, must first be carefully dried in a desiccator, or better in an electric oven at a temperature below 100° C. It may then be allowed -- in the case of thoroughly dry oil -- to slowly absorb the oil to be tested. This may be done in vacuo or, after carefully separating the pieces by wires or other means, the papers may be held on edge and allowed to touch the oil surface. The oil will then be drawn up by capillary attraction, driving out any air as it rises. By this process no air bubbles will be trapped in the test piece.

In case the oil contains any moisture, a definite amount of the mixture must come in contact with each test piece. This is accomplished by the apparatus shown in Fig. 3. The dried test pieces are placed on a fine wire screen, which is supported evenly above the bottom of a pan, which

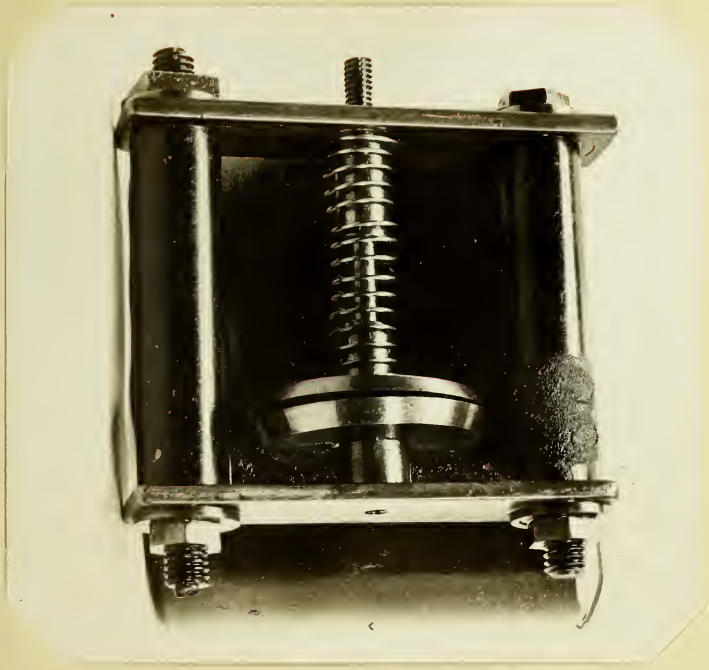


FIG. 1

OIL TEST APPARATUS

Showing

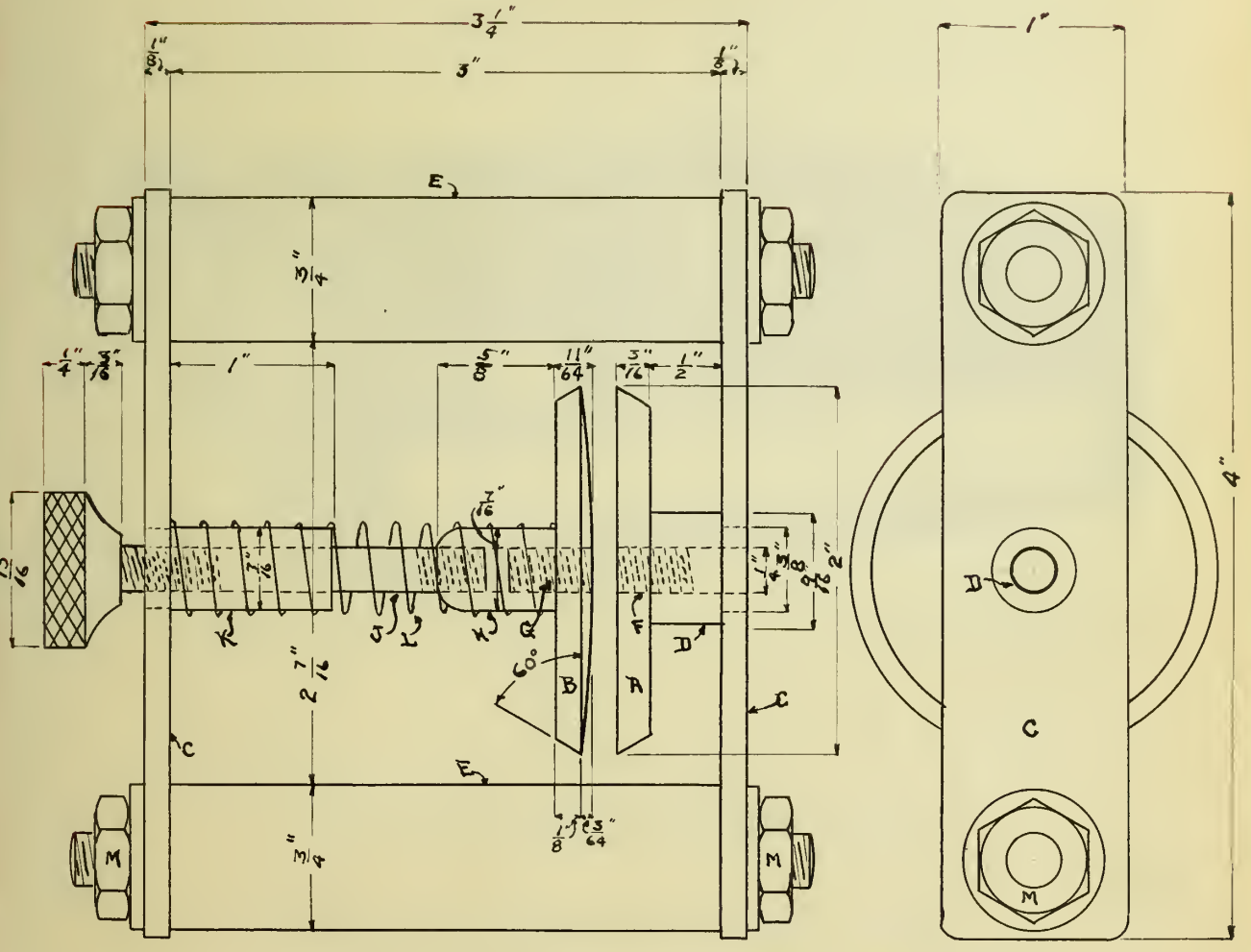
Electrodes between which Oil Soaked Blotting Paper

is placed and tested under Oil

OIL TEST APPARATUS.

Full Scale.

FIG. 2.



A. Plane Electrode.

B. Spherical Electrode. 12" rad.

C. Brass Sides.

D. Turned Block soldered into C.

E. Ebonite Rods.

F. Screw soldered into A.

G. Screw soldered into B.

H. Turned Block holding Electrode.

J. Rod carrying Electrode.

K. Sleeve soldered into C.

L. Steel Spring.

M. Nuts holding Sides on Rods E.

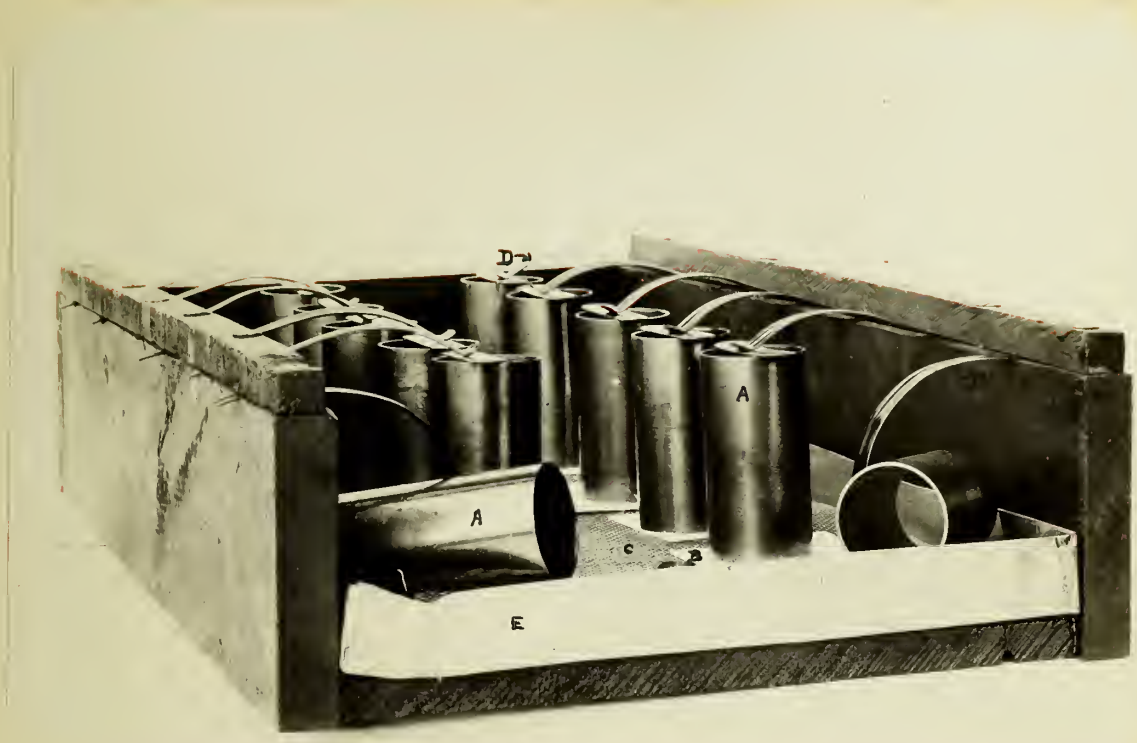


FIG. 3

FILTER TUBE APPARATUS FOR MOISTURE TEST

A - Brass Tubes into which oil sample is poured

B - Square of Blotting Paper in place beneath tube

C - Wire Screen under paper

D - Springs for holding Tubes in place

E - Pan for catching oil which has filtered through paper

is preferably drained. If it is not drained, the screen should be far enough above the bottom to clear the oil after it is filtered through the paper. On each paper is placed, on end, a small brass tube large enough to hold the amount of oil decided upon; and this tube is held firmly in place by the flat, finger springs projecting from the sides of the box. They should be stiff enough to hold the filter tubes firmly against the test pieces so that the oil will filter through the paper and not flow over the surface. 50 c.c. of oil were used in these tests and the filter tubes were cut 3" long from $1\frac{1}{2}$ " brass tubing.

The oil and water should then evenly distribute itself throughout the paper and give uniform test results. If, however, any considerable amount of water is present, it will show in light blotches on the paper which may not disappear for several hours. If tested in this condition, the sample will almost invariably break down at one of these spots and at a lower voltage than the other test pieces which have been allowed to stand till the surface appears uniform.

No reason is apparent why these test pieces should be soaked in dry oil previously to being subjected to the above process, as was suggested by Mr. Bennett. Tests made using both of these methods failed to show any difference in the results of the two methods, or in the deviation of any readings from the mean. Since water has a greater surface tension than oil, it should entirely displace the oil from the blotting paper in either procedure. As will appear later, this is not the case, more or less of the moisture passing through with the oil.

Throughout the tests a smooth core alternator was used, giving a sine wave of e. m. f., and it was connected direct to the transformer.

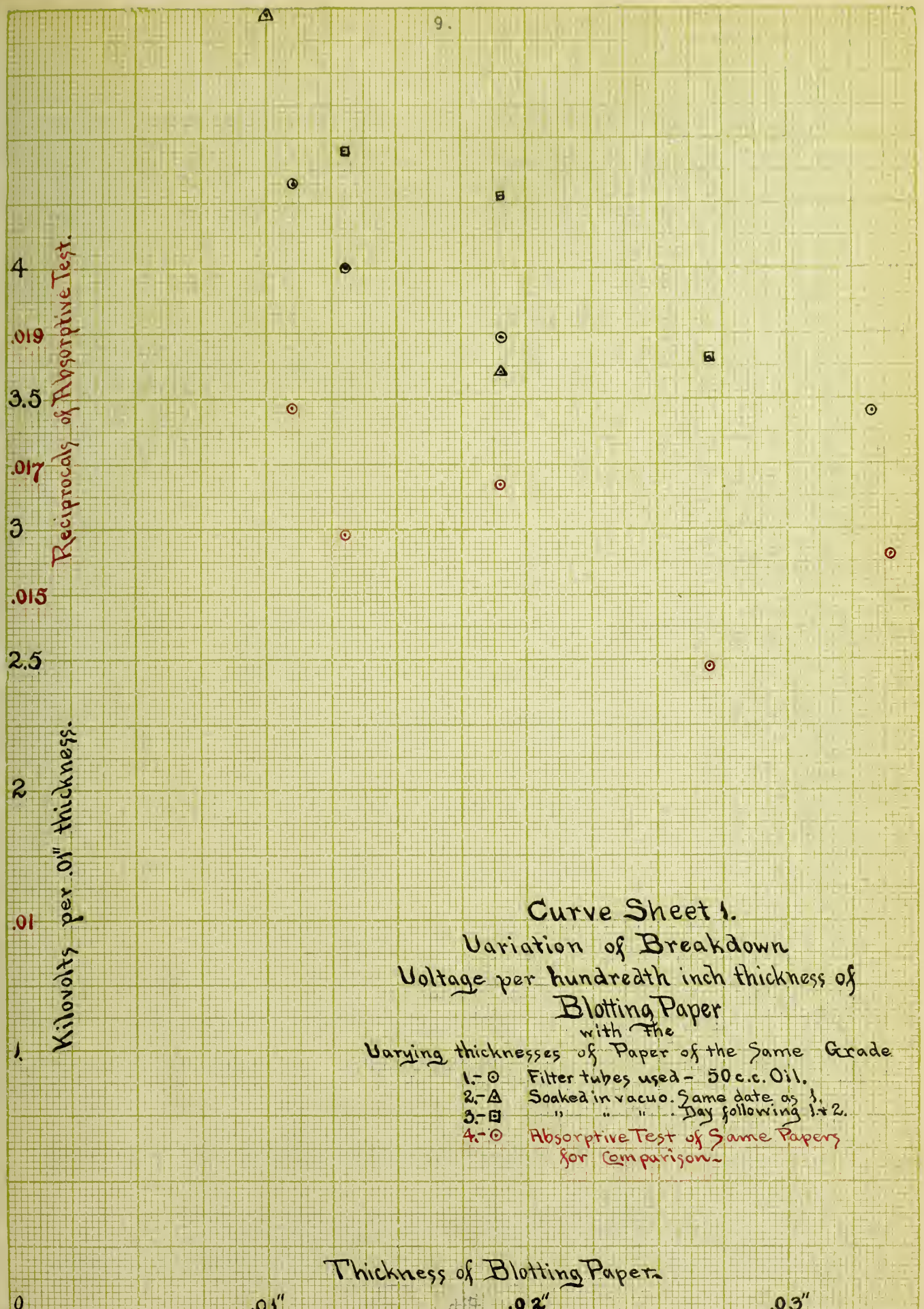
It was run at approximately 60 ~. The values of voltage given are the effective values. They were calculated by multiplying the readings of a Weston voltmeter connected on the primary side of the transformer, by the previously determined ratio of transformation.

III. TESTS OF VARIOUS KINDS OF PAPER

One of the first statements that challenged attention was that the increased strength of oil under test by the proposed method, was not at all due to the fibres of the paper. This was believed proven by the fact that pin-holes through the paper did not in any way alter the breakdown voltage required. If the above were true, it would seem that there should be no difference in the results with different kinds of blotting paper when the same oil is used.

As different papers would undoubtedly vary in thickness, it would be desirable to know how the potential for rupture would vary with the thickness of the paper, using some one grade of paper for the test.

A comparatively pure paper whose composition is approximately known was procured in thicknesses ranging from .01" to .033". The tests are not consistent as may be seen by reference to the accompanying Curve Sheet 1. The voltage per hundredth of an inch necessary for breakdown seems in general to decrease somewhat with increase in thickness of paper. But it is very doubtful if the papers are entirely alike in texture. Con-



Curve Sheet 1.

Variation of Breakdown Voltage per hundredth inch thickness of Blotting Paper with the Varying thicknesses of Paper of the Same Grade

1.- ⊙ Filter tubes used - 50 c.c. Oil.
2.- △ Soaked in vacuo. Same date as 1.
3.- ⊡ " " " Day following 1. & 2.
4.- ⊙ Absorptive Test of Same Papers for Comparison.

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siderations which will be discussed later lead to the conclusion that the test really indicates practically a constant value. The same results are shown in tests made with 1, 2, 3, and 4 thicknesses of the same paper, as given below.

.011" Paper with Dry Oil

No. of Samples Tested	No. of Sheets in Each Sample	Breakdown Voltage per .01"	Deviation in % Pos.	Neg.
6	1	4320	16	12
4	2	4400	4	2
5	4	4340	6	10
1	5	Breakdown occurs around edge		

.022" Paper, Different Quality from Above,

Tested with Oil Containing Considerable Moisture

No. of Samples Tested	No. of Sheets in Each Sample	Breakdown Voltage per .01"	Deviation in % Pos.	Neg.
5	7	1880	8	8
5	2	1900	18	13
3	3	1910	$2\frac{1}{2}$	8

The thinnest sheets which show the greatest variation from the rule were not used in any of the other oil tests. The results have therefore all been reduced to the breakdown voltage per .01" thickness of paper -- hereafter designated $V_{.01}$ -- by dividing the breakdown voltage obtained, by the thickness of the test piece in hundredths of an inch. The pieces used in the test were practically all between .02" and .03" thick.

Before beginning the oil tests with different grades of blotting paper, an attempt was made to analyse several papers. The analysis must

be partly chemical to determine the loading and filler, and partly microscopic to determine the fibre. No one was found who was familiar with the microscopic tests. The "make up" of the papers given later is, therefore, the formula given by certain manufacturers for their products. Blotting papers are, in general, made from rag, sulphite wood pulp, and mineral (clay) filling in different proportions.

Evidently it would be desirable to obtain a paper free from any ingredient which could dissolve in or mix with the oil, especially if it formed an electrolyte. It was only after considerable testing work had already been done that the paper designated "#1" was found, otherwise this would have been used for the most of the work. A number of different papers which will be designated #1, #2, #3, etc., were tested with a certain grade of oil for breakdown voltage, and were also tested by the U. S. Bureau of Chemistry test for absorptive power.

The approximate compositions of Numbers 1 to 6 inclusive furnished by the manufacturers are as follows ----

#1 is a special blotting paper manufactured for chemical purposes and guaranteed to contain absolutely nothing but cotton fibre;

#2 a commercial blotting paper manufactured by the same firm, also said to be entirely cotton fibre, but not guaranteed absolutely free from impurities;

#3 "Mosaic" -- a paper finished with a ribbed surface, said to contain 95 % cotton rag fibre, 2 % talc loading, and 3 % Soda chestnut wood pulp;

#4, #5, and #6 Three products of one mill containing respectively 90 %,

70 %, and 40 %, of cotton rag, the remainder largely soda wood pulp and some clay--about 10 % in the 70 % rag paper and probably more in the 40 %. A 25 % rag paper of the same make was said to contain 20 % clay.

The other numbers are papers the composition of which was not known. From some rough approximate tests made on

#7 it is apparently almost all cotton fibre, while the remaining samples have considerable wood pulp.

Tests were made on the absorptive power of these papers, using the method given in Circular #34 of the Bureau of Chemistry of the Department of Agriculture. A strip of the blotting paper 15 mm. wide is made to just touch a water surface. The height in millimeters to which the water rises in the paper in 10 minutes is taken as a measure of the absorptive power. The thickness is not specified. A number of different thicknesses of #2 paper were tested, the same paper used in the test for variation of breakdown potential with thickness.

It seemed probable that there might also be a difference in absorptive power depending on the way the strips were cut, whether with or across the grain of the paper. This experiment was tried, strips being cut in both directions. In all cases except in that of the thinnest paper, .011", a decided difference was noted amounting to as much as 6 mm. in some cases. The means of a number of readings taken in both directions and at different times follow. There are evidently variables in this test, very likely due to variations of the paper itself, for tests made at different times on samples supposed to be the same differ by several per cent. Tests

of two strips cut side by sice and tested at the same time may differ by 2 or 3 mm.

Thickness of paper	.011"	.013"	.019"	.027"	.03"	.034"
Height of water in mm.	56	63	60	72	62	64

This shows no uniform variation with thickness and probably simply means a variation in texture. Tests made with strips varying in width from 8 mm. to 30 mm. show that the width of the strip has no appreciable effect on the height to which the water will rise. Evidently, every run of paper must be tested.

Comparing now the various grades of paper as to absorptive power, the following results were obtained.

	#1	#2	#3	#4	#5	#6	#7	#8	#9
	75	62	75	89	74	52	67	52	58
	82	63	73	95	73	53	68	62	
	74	68		91	69	54	69	61	
	77	59		85	70	55	69		
	75	58		84	68	54			
Av.	76.6	62	74	88.8	70.8	53.6	68.2	58.3	58

These tests were made at various times and no account is taken of the grain of the paper.

A similar test made with a rather heavy oil, time 20 min., with certain of these papers gave similar relative values.

#2	#3	#4	#7	#8	#9
25	30	25	22	23	22

The heights being considerably less, the results are even less accurate than with water.

Tests for Several of the Above Papers for Breakdown - The Same Oil Being Used Throughout Any One Test

First Test - Made by soaking pieces of blotting paper in a light oil (probably kerosene) in a fairly high vacuum. A measurement of thickness of each piece was made and each breakdown voltage reduced to voltage per .01" thickness ($V_{.01}$). As may be seen from this test, the variations in readings were not reduced by this method, i. e., often a thicker piece would break down at a lower voltage. Therefore later tests were reduced only by taking a mean thickness and dividing mean breakdown voltage by this mean thickness.

Paper #2

Test piece no.	Breakdown Voltage	Thickness	$V_{.01}$
1	10300	.0285"	3600
2	11200	.0275	4070
3	11200	.028	4000
4	11200	.027	4150
5	10850	.028	3900
6	9900	.0305	3240
		Mean,	3830

Maximum deviation from mean, $+8\frac{1}{2}$ %
-15.3 %

Paper #3

Test piece no.	Breakdown Voltage	Thickness	$V_{.01}$
1	8200	.02 "	4100
2	9700	.02	4850
3	9300	.02	4650
4	9100	.0205	4450
5	9100	.02	4550
6	8750	.02	4370
7	9100	.0195	4650
8	9700	.0205	4750
9	10300	.0205	5000
10	8200	.0205	4000
		Mean,	4540

Maximum deviation from mean, +10 %
-12 %

Paper #7

Test piece no.	Break-down Voltage	Thick-ness	$V_{.01}$
1	9900	.0205"	4800
2	10200	.0217	4700
3	9900	.021	4700
4	9600	.021	4600
5	8200	.0205	4000
6	10300	.021	4900
7	10100	.022	4600
8	9800	.0215	4550
9	9100	.022	4150
10	10500	.022	4800
		Mean,	4580

Maximum deviation from mean, +7 %
-12.6 %

Paper #8

Test piece no.	Break-down Voltage	Thick-ness	$V_{.01}$
1	10300	.0195"	5300
2	13100	.0198	6600
3	11400	.020	5700
4	12200	.020	6100
5	10400	.0195	5350
6	11100	.0195	5700
7	11000	.02	5500
8	12400	.02	6200
9	9500	.0195	4900
		Mean,	5700

Maximum deviation from mean, +15.8 %
-14 %

Paper #9

Test piece no.	Break-down Voltage	Thick-ness	$V_{.01}$
1	12500	.0205	6100
2	12000	.02	6000
3	15000	.0205	7300
4	10100	.0205	4950
5	9500	.0205	4650
6	10800	.0205	5250
7	12700	.0205	6200
8	14600	.0205	7150
9	14100	.021	6700
10	16000	.0205	7800
		Mean,	6210

Maximum deviation from mean, +25.6 %
-25.1 %

Second Set of Tests - Made with "AA#8" oil, an oil sent for for use in a 200,000 Volt testing transformer. Oil taken from barrels as shipped.

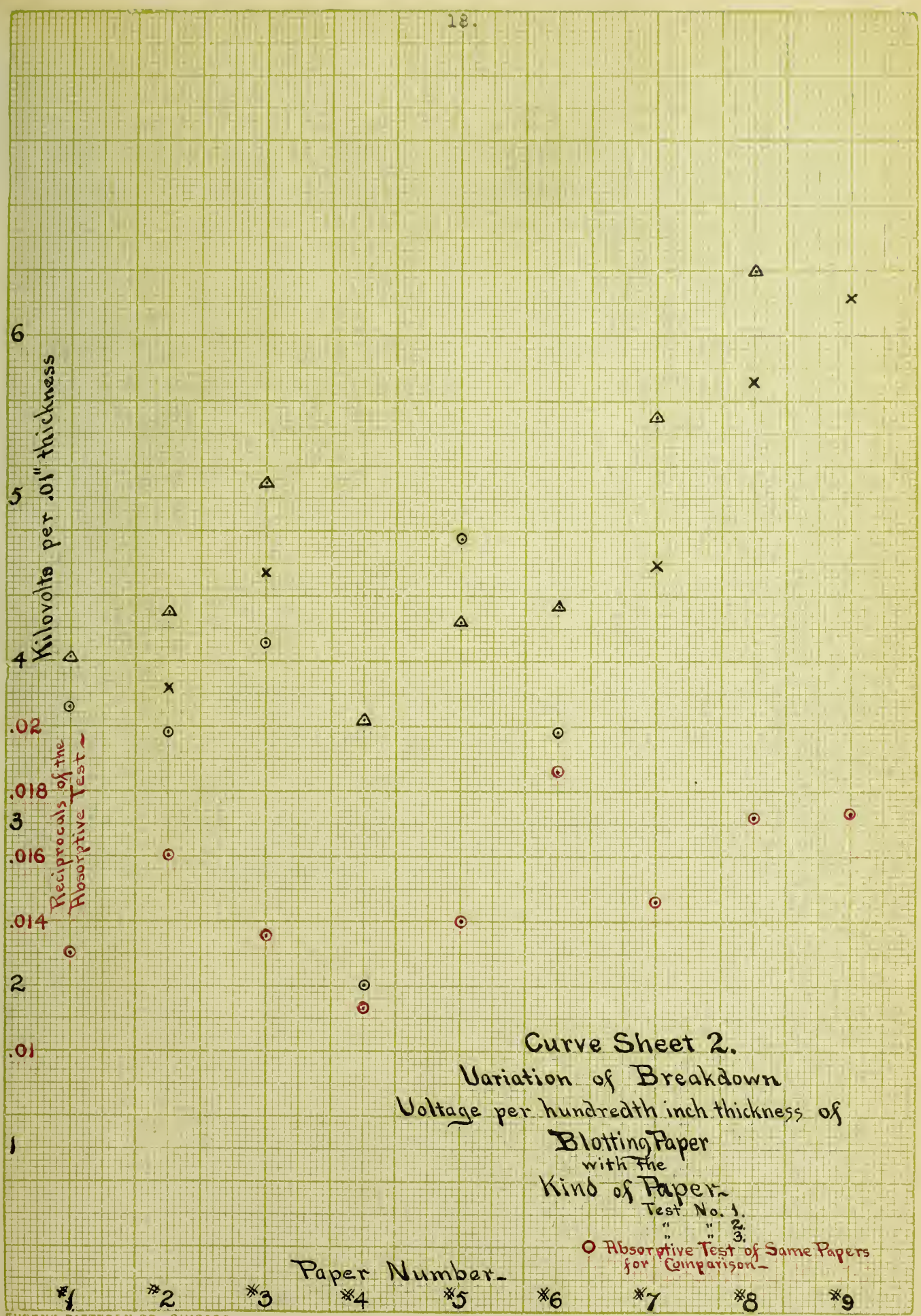
No. test	Breakdown Voltage	$V_{.01}$
Paper #1-Mean Thickness .0312"		
1	11600	3720
2	11600	3720
3	12800	4100
4	10300	3300
5	11400	3660
	Mean,	3700
	Maximum deviation,	+10.8 %
		-10.8 %
Paper #2-Mean Thickness .03"		
1	11400	3800
2	9700	3230
3	11400	3800
4	10100	3370
	Mean,	3550
	Maximum deviation,	+7 %
		-9 %
Paper #3-Mean Thickness .022"		
1	10450	4750
2	8200	3730
3	8350	3800
4	8750	3980
5	9700	4400
6	8900	4050
7	9100	4140
8	8350	3800
	Mean,	4080
	Maximum deviation,	+16.4 %
		- 8.6 %
Paper "4-Mean Thickness .031"		
1	7400	2390
2	6650	2140
3	6100	1980
4	5300	1710
5	5500	1770
6	6100	1980
	Mean,	1990
	Maximum deviation,	+20.1 %
		-14.1 %
Paper #5-Mean Thickness .023"		
1	10250	4450
2	10700	4650
3	10800	4700
4	11800	5150
5	10400	4500
6	12150	5300
	Mean,	4790
	Maximum deviation,	+10½ %
		- 7 %
Paper #6-Mean Thickness .027"		
1	8950	3320
2	8900	3300
3	11400	4230
4	11000	4080
5	7600	2820
	Mean,	3550
	Maximum deviation,	+19 %
		-20½ %

Third Test - Using "AA#8" oil dried in vacuo, made with from 5 to 7 pieces of each make. The variation from the mean was somewhat less than in the preceding tests. Only the mean values of $V_{.01}$ and the deviations are given.

Paper	$V_{.01}$	Deviation Positive	Deviation Negative
#1	4000	13.4 %	14.6 %
#2	4300	3.	6.
#3	5100	7.	8.8
#4	3620	4.5	5.6
#5	4250	11.5	13.4
#6	4350	8.	8.
#7	5500	19.5	12.
#8	6400	14.2	15.1

Plotting values of the breakdown voltage found for the various types of papers in the above tests, and also the values of the reciprocals of the absorptive power, it is seen that (with the exception of the special paper with corrugated surface #3 and #6) the relative values vary roughly in the same manner. (See Curve Sheet 2.)

This perhaps means that the absorptive power largely depends upon the porosity of the paper, and that the more porous paper offers a lower resistance path for the passage of current through the oil absorbed in it. Whether this has any effect on regularity of test, because allowing more chance for lining up of bubbles or moisture, it would be hard to say. It does not appear so from the tests, and Mr. Bennett did not find any difference between papers with or without pin holes. Yet it does appear that there is a difference in the values obtained with different grades of paper, tending to show that the paper does have an influence on the breakdown voltage.



Curve Sheet 2.

Variation of Breakdown Voltage per hundredth inch thickness of Blotting Paper with the Kind of Paper.

Test No. 1.
" " 2.
" " 3.

○ Absorptive Test of Same Papers for Comparison.

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Still it must be admitted that the individual variations and the variations between different tests are often greater than the differences of the mean values plotted.

Returning now to Curve Sheet 1, there will be noticed a series of points in red. These points are the reciprocals of absorptive powers given on page 10 for these different thicknesses. It will be noted that these values are related to the voltage much as those discussed above. That is, the variations noted in these papers are probably not due to variations in thickness but to variations in texture. (See page 8.)

It is evident that the tests as carried out do not show great gain in exactness of measurement.

#1 Paper would be used in any future tests due to its guaranteed purity, but many of the following tests were made before this was secured and no large quantity has been had at any time. The General Electric Company, however, advised the use in their filter purifier and drier of a wood pulp paper.

IV. TESTS FOR MOISTURE

Several tests were made to determine the moisture content of oil. An oil known as "AA#8", recently shipped from the General Electric Company for a 200,000 Volt Transformer was used. It was presumably dry and was taken as a standard with which known percentages of water could be mixed. It had, however, been exposed to the air and poured from one vessel to another. It is difficult to see how an engineering test of the dielectric strength of oil can be made, if the experimenter must observe all the precautions asserted to be necessary, to prevent oil absorbing moisture from the air. No special care was taken along this line, as the test pieces and containing jar of oil were necessarily open to the air during the testing process. Amounts of water up to .1% were added, care being taken to thoroughly shake the mixture each time before using. The blotting paper samples were those impregnated by the use of the "filter tubes" as outlined above, and tested for dielectric strength. Certain of these tests follow.

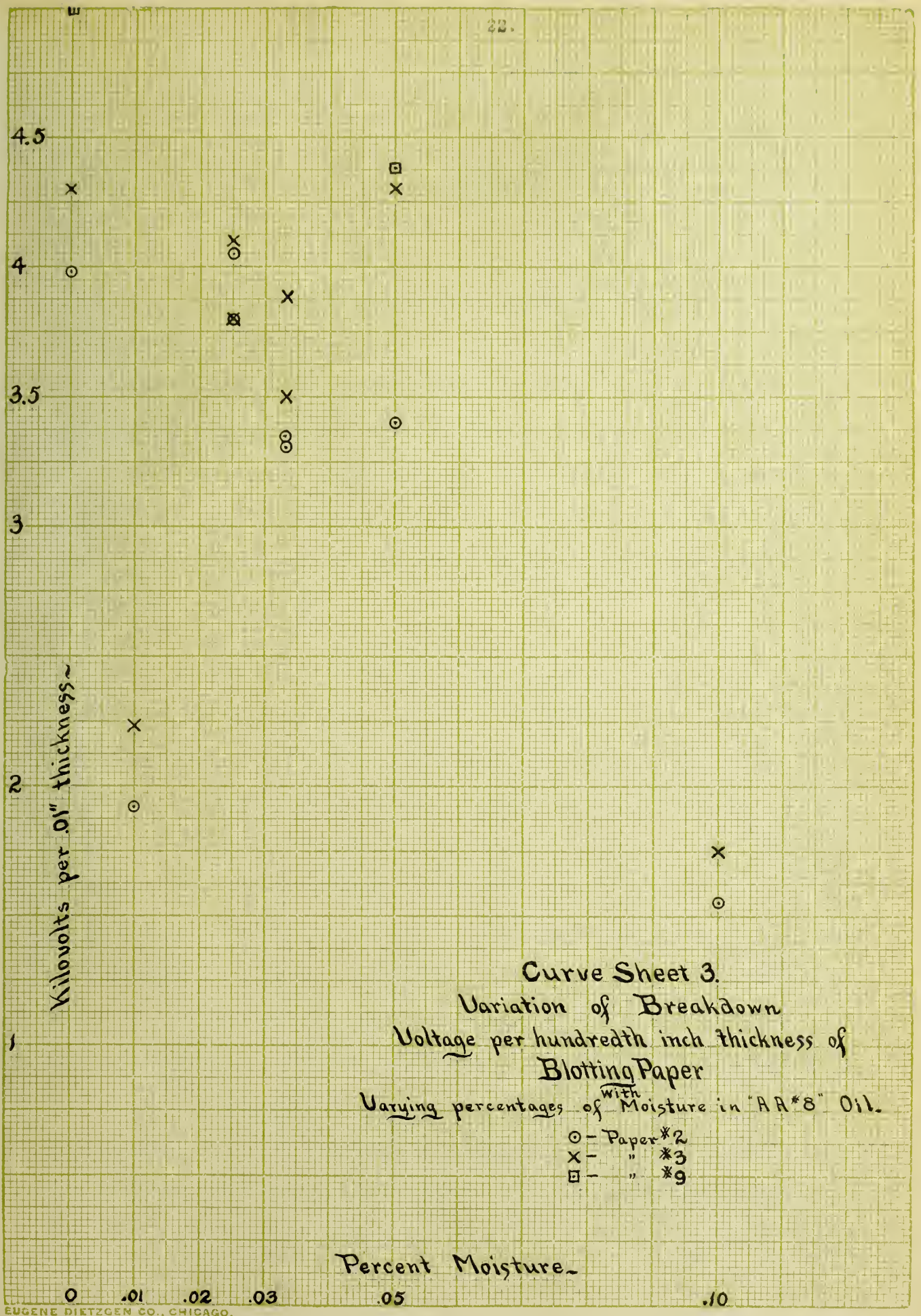
In general 6 pieces were used for each different condition of moisture content and each kind of paper. Sometimes one piece would have to be rejected on account of some defect. The mean values and maximum deviations are given below.

% Water	Paper	$V_{.01}$	Deviation in %	
			Positive	Negative
0	#2	3980	$15\frac{1}{2}$	$9\frac{1}{4}$
"	#3	4300	$9\frac{1}{2}$	$9\frac{1}{2}$
"	#9	5040	$10\frac{1}{2}$	7
.01	#2	1920	8	$11\frac{1}{2}$
"	#3	2230	$14\frac{1}{2}$	13

% Water	Paper	$V_{.01}$	Deviation in % Positive	Negative
.025	#2	3800	8	13
"	#3	3800	24	39
* "	#2	4050	3	4 3/4
* "	#3	4100	5	9 1/4
.033	#2	3310	16	25
"	#3	3860	5 1/2	4
* "	#2	3350	2	4
* "	#3	3500	10 1/2	8
.05	#2	3400	13 1/2	16 1/2
"	#3	4300	5 1/2	5 1/4
* "	#9	4380	30 1/2	21
.1	#2	1550	26 1/2	18 1/4
"	#3	1750	3 1/4	4

*Tests marked thus were made with paper previously soaked in dry oil.

In the last case, the water could not be thoroughly mixed with the oil; drops would settle almost immediately to the bottom of the bottle. The papers were covered with white blotches when first removed from under the filter tubes, and it was only after long standing that the test could be made. No data could be secured with larger amounts of water. The test with .01% water was taken some days after the others of the series. Curve Sheet 3, on which these values are plotted, shows how far these results come from falling on a line.



Curve Sheet 3.
Variation of Breakdown
Voltage per hundredth inch thickness of
Blotting Paper
Varying percentages of Moisture in "AA*8" Oil.

⊙ – Paper *2
× – " *3
⊡ – " *9

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V. DRY OIL

In the preceding test it was assumed that the oil was dry. As was suggested, it is neither easy to get dry oil, nor to keep it dry once it has been freed from water. Neither is it a simple matter to test for very small moisture percentages. Possibly the most delicate test is the electric. To use that here would be begging the question. It is therefore uncertain just what percentage of water each sample did contain in the above test. Much of the time consumed during these experiments was spent in an endeavor to secure dry oil.

No one of the commercial driers in which oil is forced through blotting paper, was available. The use of chemical driers in the oil had been extensively tried by Mr. Bennett, and had been given up, due to the formation of electrolytes in the oil. He had also shown that the surface tension for minute bubbles was so great that no obtainable vacuum would avail to remove them. Heat, however, considerably reduces this surface tension, and it was thought that dry oil might be obtained by a combination of heat, a low pressure and constant agitation. With this in view, a large vacuum desiccator was obtained into which was fitted a series of shallow pans, and in the bottom was put phosphorus pentoxid. Through the rubber stopper near the top was run not only the glass tube connection to the vacuum pump and the manometer, but also two wires carrying current to a small electric heater. This desiccator was mounted on a platform which was continuously tilted up and down by a cam. This produced a continual series of waves in the oil which

was placed in the shallow pans. A vacuum of a very few millimeters was obtained, and a temperature of 40° or 50° C. was maintained. This changed the oil sometimes appearing to give it greater strength. But it was very apt to darken the oil, showing decomposition and deposition of carbon. The probability of this trouble had in fact been foreseen. When, however, oil to which water had been added was treated in the desiccator and then tested, it did not appear that any appreciable amount of moisture had been removed, even after several hours of treatment. It seems that this method of drying is not practicable and that some filter such as is for sale by the various electrical companies must be resorted to.

VI. APPLICABILITY OF METHOD

It is a question whether, after securing thoroughly dry oil, this method of test will prove satisfactory, since, in any test where moisture is suspected, it requires the blotting paper and oil spread out over a considerable surface, to be exposed to the air for some hours. The possibility of making any arrangement of apparatus which would allow of manipulation in an atmosphere which would neither add to nor subtract from the moisture of the test piece seems doubtful. In the case of large per cents of water this exposure may need to be 5 to 10 hours to allow time for the test piece to become uniform. What proportion of the moisture is soaking into the paper and what evaporating into the air is problematical.

When, on the other hand, very small moisture percentages, less than .01%, are to be measured, the method appears not sensitive enough, unless larger amounts of oil should be filtered through each test piece. This again would require a longer time and more exposure to the air. On page 7, the statement was made that blotting paper should take from oil all of its moisture since water has the greater surface tension. However, when oil is filtered through a single thickness of paper, as done in these tests, it seems that by no means all the water is removed. For example, the oil, which contained originally .05% water, was recovered after it had been filtered through #2 and #3 papers for the test tabulated on page 21 , and was again put through similar test pieces with the following results:

Paper #2,	$V_{.01}$ = 3570	Deviation, +8%, -15%
" #3,	" = 3800	" +12½%, -12½%

These are considerably lower values than those obtained from the original dry oil which had been used for making up these wet samples, (see page 20), but higher than the .05% water test referred to. It must be admitted that the variation in individual readings is again greater than the difference between the means.

Again, a sample of oil to which had been added .5% water was run through test pieces. The results were too variable and unreliable to use at all. The filtrate was again used, giving these values:

Paper #3,	$V_{.01}$ = 3530	Deviation, +10%, -20%
" #9,	" = 4660	" +20%, -20½%

The filtrate from this test was again tested with the following results:

Paper #3,	$V_{.01}$ = 3550	Deviation, +11%, -13%
" #9,	" = 3800	" +22½%, -13½%

The original test of this oil before any water had been added was:

Paper #3,	$V_{.01}$ =	4270	Deviation, +10%, -8½%
" #9,	" =	4960	" +15%, -27%

These tests, while far from convincing, due to the large variations, seem to indicate that by no means all the moisture is taken out of the oil by the blotting paper in this method of test. Whether a proportionate amount is taken out in each case would require a more extended and more accurate set of tests to determine.

If the method is to be applied to testing the value of oils for transformer use, there is the disadvantage that the conditions are not normal. In any piece of apparatus, where oil is used, it is free to circulate. If this changes the voltage required for rupture, the strength of the oil is being judged from conditions entirely unlike those in which the oil is to be used. Further, between the two there would be no defirite relation.

VII. CONCLUSIONS

It is evident that the data obtained in these experiments are not sufficiently accordant to allow positive conclusions to be drawn. Yet certain points seem to be established.

The apparent strength of the oil is affected by the kind of paper used. The same grade of paper varies in different lots. For any series of tests which are to be compared the same lot of paper should be used. This might cause inconvenience if the tests were to cover a considerable period of time. It has not been determined how much the results are affected by changing from one lot of paper to another of the same grade and weight.

A pure paper should be used.

It seems possible to secure a greater degree of uniformity in any set of readings taken at one time than between sets taken at different times, though the experiments are performed apparently under the same conditions.

Though the same accuracy has not been attained that seems to have been secured by the previous investigator in this work, still a deviation not to exceed 25% can evidently be obtained, unless an excessive amount of water is present. This is an advance on former methods of test, for it is to be noted that all readings have been included, unless there was some evident defect, and that no refinements or precautions were taken that could not be observed in any ordinary commercial test.

It is proposed to investigate whether there is anything in the

so-called pure blotting paper which will affect the oil. This will be done by conductivity measurements of pure water in which the paper has been soaked, and also, if possible, of oil treated in the same way. Analytical tests should also be made. If a suitable paper is found, this alone will be used, and a number of duplicate tests run at different times. If it then appears that sufficient accuracy can be attained and that the results are reasonably consistent, it will remain to procure oil known to contain a negligible amount of moisture and to make series of tests of oil with various moisture contents, and to compare curves so obtained with different qualities of oil. If these tests are satisfactory, a general law of the effect of moisture in oil as indicated by this method may be formulated.

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